General Notes and Program Limitations

For

RAPID Version 3.0

The RAPID Version 3.0 program performs static strength and damage tolerance analysis of a repaired or modified fuselage skin due to damage or an antenna installation. The repaired skin involves a damage treatment of the skin cutout and replacement of the removed skin with repair doublers mechanically fastened to the skin. The modified skin for antenna installation involves a skin cutout and installation of a doubler riveted to the skin and an antenna mounting plate bolted to the skin through the doubler. The following addresses the analysis capability of the current version of the program.

(A) General

1. Analysis for repaired or modified skin is restricted to areas between forward and aft pressure bulkheads, but away from door cutouts, window cutouts, and window belt structure. This is also not applicable to pressure bulkheads or flat pressure panels.

2. The fuselage is assumed to be circular with a constant radius. The repairs and antenna installations are limited to areas on the airplane where the hoop stress due to pressurization can be approximated using a cylindrical pressure vessel analysis.

3. The damage due to accidental or cracking causes in repairs and the modification to skin for antenna installations is only in one skin layer.

4. In repairs, the skin cutout and doublers can be rectangular or circular in shape. In antenna installations, the skin cutout is circular and the doubler and mounting plate can be in a circular or rectangular shape. For rectangular repairs and antenna installations, the orientation is such that two of the four sides are in the hoop stress direction and the other two are in the longitudinal stress direction.

5. Repair configurations are confined to the following types:

   Rectangular repairs:

   - Type 1: One internal and one external doublers
   - Type 2: Two stack-up internal or external doublers
   - Type 3: One internal or external doubler

Circular repairs:

- One external or internal doubler

6. For Type 1 repairs, only one outstanding fastener row is allowed in the internal doubler.

7. For Type 2 repairs, only one outstanding fastener row is allowed in the external doubler next to the skin.

8. In addition, the program is capable of assessing common repairs including a repair near another repair and repairs at/near stiffeners.

9. The following restrictions are applied to the current version of RAPID program

   - For a repair near another repair:

     Only Type 1, 2, and 3 repairs are considered.

   - For repairs at/near stiffeners:

     Only Type 1, 2, and 3 repairs and repairs over splice joints are considered.

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   - For a repair at/near stiffeners in proximity of another repair:

     Only Type 1, 2, and 3 repairs are considered.

10. Repairs are limited to the following sizes

    - Skin cutout size (Add 3 ~ 5 fastener rows to determine the repair size)

      - Type 1,2,3 repairs:30” (Long.) x 20” (Circumferential)
      - Circular repairs: 5” (Radius)

    - Skin cutout size in proximate repairs

      - Subject repair: 30” (Long.) x 20” (Circumferential)
      - Proximate repair: 25” (Long.) x 25” (Circumferential)

11. The static strength and damage tolerance analyses are limited to material and fastener databases available in current version of RAPID program.

12. RAPID excludes the case of skin bending induced by antenna vibrations subjected to aerodynamic loading. Therefore, communication antennas (typically 5” long by 3” wide by 10” tall) are excluded. However, antenna systems such as ADF (12” long by 6” wide by 1” tall), GPS (4” long by 4” wide by 0.5” tall), Transponder and DME (5” long by 2” wide by 4” tall), and TCAS are included.

13. Antenna installation configurations are confined to one internal or external doubler and a mounting plate. The size of antenna connector hole cutout in skin and doubler is limited to 1.0” ~ 3.0” in diameter. For circular configurations, a maximum of 3 fastener rows is allowed. For rectangular configurations, the fastener rows can be 1x1, 2x2, 3x3, 3x4, and 3x5.

(B) <u>Static Strength Analysis</u>

1. Static strength analysis is performed using the fastener joint allowable, the doubler allowable, and the shear allowable of skin and doubler. The margins of safety are calculated and flagged to testify adequacy of the repair and antenna installation. The stiffness ratios between the doubler(s) and skin layers are checked and flagged to indicate whether the repair/antenna installation is too stiff or not stiff enough.

2. The load carrying capacity lost due to skin cutout is calculated using the design ultimate tensile stress and cutout size of the skin.

3. The database of fastener joint allowable is built using the data in the MIL-HDBK-5F.

(C) <u>Damage Tolerance Analysis</u>

1. In the repaired or modified skin, fastener loads along the critical outermost row are obtained using the two-dimensional finite element analysis. The fastener shear stiffness is determined using the Swift’s equation (Reference 1). For crack growth analysis of a crack initiating at the antenna connector hole, the stress gradient along the potential crack growth path normal to the stress application direction is also obtained. It is noted that fastener loads and the stress gradient are calculated for the un-cracked repaired or modified skin configuration; and are assumed to remain constant in the damage tolerance analysis.
2. Damage tolerance analysis is performed for both longitudinal and circumferential through cracks emanating from the critical fastener holes in the outermost fastener row. Analysis is also performed for a crack initiating at the antenna connector hole in antenna installations.

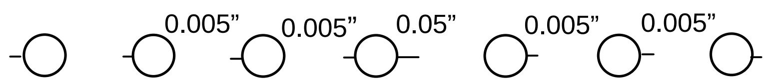
3. The crack geometry is assumed to be through crack. Assumptions of initial crack geometry and subsequent crack growth are described as follows.

(A) Repairs

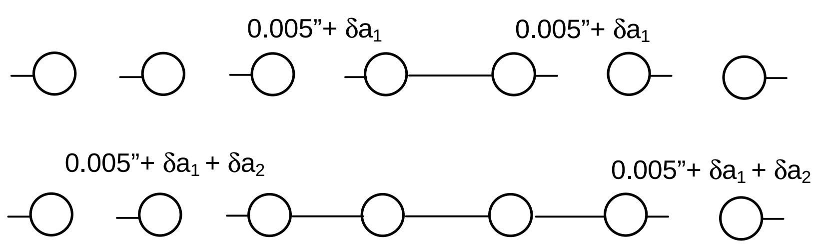
(i) Type 1, 2, and 3 repairs

Scenario 1: Center fastener hole in the outermost fastener row

<u>Initial crack</u>: Two diametric through cracks of lengths 0.05” and 0.005”, respectively, emanating from the center fastener hole together with a 0.005” crack at one side of every other hole

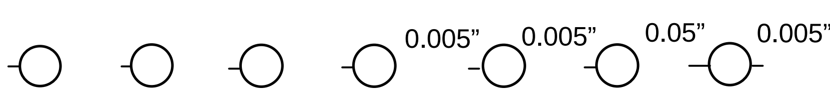


<u>Subsequent damage</u>: All cracks grow concurrently but independently, interaction between cracks being ignored. The amount of growth δa_1 for the 0.005” crack is added to its original length when the 0.05” crack grows into the adjacent hole. The same process continues in successive growth.



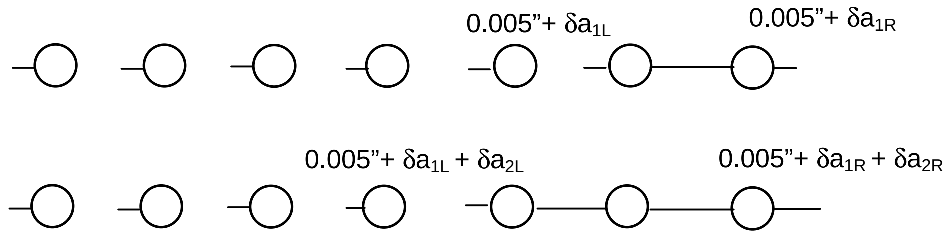
Scenario 2: Corner fastener hole in the outermost fastener row

<u>Initial crack</u>: Two diametric through cracks of lengths 0.05”, pointing toward the adjacent hole, and 0.005”, respectively, emanating from the corner fastener hole together with a 0.005” crack at one side of every other hole



<u>Subsequent Damage:</u> All cracks grow concurrently but independently, without interaction between cracks being considered. The amount of growth δa for the 0.005” crack is added to its original length when the 0.05” crack grows into the

adjacent hole. The same process continues in succession growth.

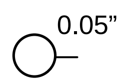


It is noted that successive growths of the 0.005” at corner fastener hole δa_{1R}, δa_{2R}, etc. are different from the growths at other holes δa_{1L}, δa_{2L}, etc. because the former does not grow toward an adjacent hole but others do.

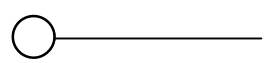
(ii) Circular repairs

Scenario 1: Outermost fastener hole

<u>Initial crack</u>: A through crack of length 0.05” at the12 o’clock fastener hole



<u>Subsequent damage</u>: The crack grows in skin



(B) Antenna installations

(i) Rectangular configurations

Scenario 1: Center fastener hole in the outermost fastener row

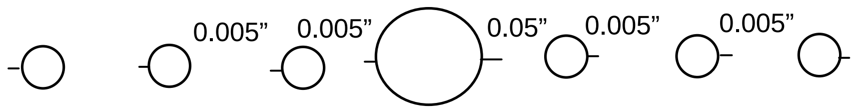
Same as in Type 1, 2, and 3 repairs

Scenario 2: Corner fastener hole in the outermost fastener row

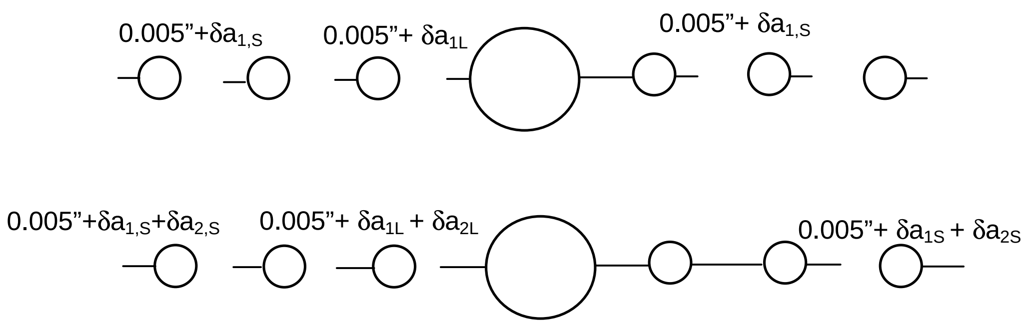
Same as in Type 1, 2, and 3 repairs

Scenario 3: Antenna connector hole

Initial crack: Two diametric through cracks of lengths 0.05” and 0.005”, respectively, emanating from the antenna connector hole together with a 0.005” crack at one side of every other hole



Subsequent Damage: All cracks grow concurrently but independently, ignoring interaction between cracks. The amount of growth δa for the 0.005” crack is added to its original length when the 0.05” crack grows into the adjacent hole. The same process continues in successive growth.



It is noted that successive growths of the 0.005” at antenna connector hole δa_{1L}, δa_{2L}, etc. are different from the growths of 0.005” crack at fastener holes δa_{1S}, δa_{2S}, etc. because the hole sizes and fastener pitches are different.

(ii) Circular configurations

Scenario 1: Outermost fastener hole

Same as in circular repairs

Scenario 2: Antenna connector hole

Same as in rectangular antenna installation configurations

4. Three types of stress intensity factor solutions are implemented in RAPID program:

(1) Basic solutions from literature

- A through crack emanating from a hole in a wide plate
- A through crack approaching a hole in a wide plate
- A through crack growing towards a stiffener in a wide plate
- A through crack at stiffener growing towards adjacent stiffeners in a wide plate
- A through crack between two stiffeners growing towards adjacent stiffeners in a wide plate

(2) Estimated solutions derived from basic solutions using the compounding method

- A through crack passing through two or more holes

(3) Numerical solutions for one or two diametric through cracks at a hole under arbitrary stress gradient on crack faces

The interference-fit and neat-fit-pin effects are ignored.

5. Bulging is considered for rectangular, circular, and splice joint repairs. Equations provided by the FAA were used in the program.

6. Residual strength of the repaired skin is calculated using the fracture toughness approach with Fedderson's method for small cracks. In this method, a tangent line from the yield stress of the material to the residual strength curve obtained from the fracture toughness approach is numerically obtained to compose the residual strength of the repaired/modified skin.

7. The crack growth analysis can be performed using either the simplified method, or the cycle-by-cycle method with or without the retardation effect in the analysis. When the retardation effect is considered, it is accounted for by using the generalized Willenborg retardation model.

8. In the simplified method, the da/dN rate data are represented by the Walker's equation (Reference 2). Coefficients in the Walker's equation are reduced for the following 13 materials:

   - 2024-T3 Clad Sheet, -T42 Bare Sheet, L-T RT LA DW

- 2024-T3 Clad Sheet, -T42 Bare Sheet, T-L RT LA DW
- 2024-T3 51 Plate, -T3511 Extrusion, L-T RT LA DW
- 7050-T7452 Forging, L-T T-L LA RT
- 7050-T74511, -T76511 Extrusion, L-T RT LA DW
- 7050-T74511, Extrusion, L-T RT STW
- 7050-T7651, -T7451 Plate, L-T T-L RT LA DW
- 7050-T76511, Extrusion, L-T RT STW
- 7475-T7351, Plate, L-T LA RT
- 7475-T7651, Plate, L-T LA RT DW
- 7475-T761, Clad Sheet, L-T RT LA DW
- 7075-T6, Clad Sheet, L-T RT LA
- 2014-T6 Sheet, T = 0.05, L-T RT LA 10Hz

In the cycle-by-cycle method, table lookup of the da/dN rate data is used in the analysis. RAPID also accept user-supplied da/dN data.

9. Generic load spectra for narrow and wide body aircraft are generated at the fuselage C.G. location. RAPID converts the load spectrum into the stress spectrum near the repair location for the crack growth analysis. The user can also provide RAPID with the stress spectrum for analysis.

10. The limit stress in the circumferential direction, for the longitudinal crack, is calculated using the equation

$$\sigma_{Limit,Circumferential} = 1.1\frac{(p+1.0)R}{t}$$

where p is the pressure differential, R and t are the radius and thickness of the fuselage shell at the location where the damage tolerance analysis is performed. The stress due to the additional pressure 1.0 psi in the equation is to account for the external aerodynamic suction pressure per FAR 25.571.

The limit stress in the longitudinal direction, for the circumferential crack, is determined using the equation

$$\sigma_{Limit,Longitudinal} = \frac{(p+1.1)R}{2t} + 2.5\sigma_{1G} / \gamma$$

where p is the pressure differential, γ is the payload reduction factor, R and t are the radius and thickness of the fuselage shell, and σ_{1G} is the one-G stress, under normal operating condition, at the repair or antenna installation location. The pressure 1.1 psi in the above equation is added to account for a 10% increase of the 1.0 psi in the aerodynamic pressure terms as in the circumferential limit stress.

11. At completion of damage tolerance analysis, RAPID provides users with crack growth life and residual strength to help users determine inspection threshold and inspection interval.

References

1. Swift, T., “Fracture Analysis of Stiffened Structure,” Damage Tolerance of Metallic Structure: Analysis Methods and Application, ASTM STP 842, J.B. Chang and J.L. Rudd, Eds., American Society for Testing and Materials, 1984.

2. Swift, T., “Repairs to Damage Tolerant Aircraft,” Structural Integrity of Aging Airplanes, S.N. Atluri, S.G. Sampath, and P. Tong, Eds., Springer-Verlag, 1991.